IEEE P802.11
Wireless LANs

|  |
| --- |
| “Proposal for a revised Annex G containing Examples of Frame Exchange Sequences”  |
| Date: 2023-05 |
| Author(s): |
| Name | Affiliation | Address | Phone | email |
| Harry BIMS | Bims Laboratories, Inc. | Menlo Park, CA, USA. | 650 283 4174 | harrybims@me.com |

Abstract

This proposal seeks to introduce the reader to an alternative version of Annex G for describing frame exchange sequence examples, their temporal boundaries, and recommended practice based on frame exchange sequences that are specified in the P802.11-REVme/D2.1 document.

# A. Background

The Architecture Standing Committee has extensively debated the disposition of Annex G for many meetings. In the course of those discussions, the group has requested a proposed revision to Annex G that explains to the novice reader of the 802.11 standard, using informative text, the concept of frame exchange sequences, as the term is consistently used throughout the standard in various contexts. To this end, proposed text for Annex G is presented below for discussion. We may want to consider as part of the discussion the prospect of moving the informative text in clause O.3 (Example of RD frame exchanges) to Annex G, as it appears to be out of place in its current location.

The proposed Annex G presented below contains an informative description of frame exchange sequences, and their use in the normative text. The style of this proposed Annex G follows the style of other Annexes that provide exemplary descriptions of the normative text. In particular, consideration has been given to Annex I, Annex K.1, Annex L, Annex O.3, Annex Q, and Annex W.

# B. Perspectives on the frame exchange sequence time interval

For any given frame exchange sequence (FES), there can be different understandings among the peer STAs about when the FES terminates. This can affect the timing for when certain procedures are initiated. For example, according to 6.5.3.2.4, the scan process can be initiated when a frame exchange sequence is completed, according to 6.5.4.2.4, the synchronization procedure can be initiated when a frame exchange sequence is completed, and according to 6.5.11.2.4, the BSS initialization procedure can be initiated once the current frame exchange sequence is completed, and according to 9.2.4.1.7 and 9.2.4.5.11, the power management mode of a STA is initiated after successful completion of a frame exchange sequence. Nonetheless, this is not a problem as long as the peer STAs are exchanging frames on a wireless medium independent of other STAs. For example,

Persepctive #1: The STA that initiates the FES (STA #1) identifies the end of the FES as the end of a PIFS interval following the last transmission during the FES. The timing for the end of the last transmission of the FES is either pre-determined by the particular FES (e.g., an RTS / CTS exchange) or is scheduled by STA #1 (BAR frame).

Perspective #2: The peer STA to STA #1 (STA #2) identifies the end of the FES as the end of a PIFS interval following the last transmission during the FES from its perspective. This understanding may differ from STA #1. For example, if STA #1 transmits PPDUs to four different STAs (STA #2 through STA #5) during a single FES, and STA #2’s CCA function indicates the medium is idle while the BlockAcks from STA #3 through #5 are transnmitted, then STA #2 will declare the end of the frame exchange sequence a PIFS interval after its BlockAck transmission. Note, however, that the NAV protection signaled by STA #1 still prevents STA #2 from initiating any transmission until STA #5 has transmitted, regardless of CCA sensing. If STA #2’s CCA function indicates the medium is busy when the BlockAcks from STA #3 through #5 are transmitted, then STA #2 will immediately terminate its FES with STA #1 if it can decode the PPDU, per the normative text. See §11.2.6:

“The STA can determine the end of the frame exchange sequence through any of the following:

* It receives an individually addressed frame addressed to another STA.
* It receives a frame with a TA that differs from the TA of the frame that started the TXOP.

. . .

* The CS mechanism (see 10.3.2.1 (CS mechanism) indicates that the medium is idle at the TxPIFS slot boundary (defined in 10.3.7 (DCF timing relations)).”

This nuance is not currently captured in the normative text, and should be explained to the reader in Annex G where appropriate.

The following are mechanisms related to frame exchange sequences:

1. TXOP error continuation.  A STA owning a TXOP that misses a response can recover by transmission after a PIFS,  and can transmit to another STA.

2.       RDG.  Effectively transfers ownership of the balance of the current TXOP to another STA.  But that “balance” is constrained in that other STA can only talk to the original STA.

3.       HCCA.   This is a polled mechanism where the HC grants a sequence of TXOPs to other STAs.  The HC remains in control of who owns a TXOP,  and the duration of that TXOP.

4.       PSMP.  The AP indicates a sequence of downlink and uplink slots to other STAs.  There is some flexibility for recovery by the AP, but not by other STAs.

The first two mechanisms are limited by the original TXOP boundaries and apply to both STAs and APs.  The TXOP limits are determined by the AP by signalling in the beacon.

The second two mechanisms are for APs to manage the medium and are not limited to a single TXOP limit.

Note that “error recovery” is easy to specify wrongly.   There has to be an unambiguous understanding of who can transmit next during a TXOP,  otherwise it changes from a region of contention-free operation into something else.

**Annex G (revised)**

(informative)

# Examples of Frame Exchange Sequences

## Introduction

Frame exchange sequences are described in a variety of contexts throughout this standard. For example, descriptions of frame exchange sequences are generally included in the normative text of multiple clauses (i.e., 4.3.10 (describing frame exchange rules are part of the core QoS facility), 4.3.11.11 (describing link measurement a frame exchange seqeunce), Clause 10 (describing different STA Types), Clause 11 (describing a GAS frame exchange sequence), 4.3.24.5.6 and 14.6 (describing AMPE and MCCA), 4.10 (describing 802.1X frame exchange sequences), 6.3 and Clauses 26 through 28 (each describing a different peer PHY entity). Informative text descriptions of frame exchange sequences are also described in Annex O (RD frame exchanges), and Annex Y (PAD procedures). The first description of a frame exchange sequence appears in 4.10.3.3, Figure 4-34.

It is entirely possible for STAs to operate in a heterogenous environment, where there can be different peer PHY entities operating in accordance with different PHY clauses in the same geographic area. It is also possible for STAs to exchange frames across a wireless medium within the context of multiple wireless media, allowing for overlapping frame exchanges in frequency between STAs, and/or directed spatial streams between a beamformer and a beamformee.

Often, these descriptions are tailored to the specific requirements context of the clause in which they appear. For example, some frame exchange sequences are identified by a higher layer protocol (9.4.2.123), or by a peer-to-peer application (9.4.2.254). For some PHY scenarios, there is only one wireless channel instance, for other PHY scenarios, there may be several channel instances of the wireless medium, due to sectorization, beamforming, and MU-MIMO that can impact single wireless channel PHYs.

At times STAs involved in a frame exchange sequence may have different understandings among peer STAs about when an FES terminates on the wireless medium, even though in accordance with 9.2.5.2, 9.2.5.4 and 9.2.5.5, each STA’s estimated time duration of an FES determines the value of the Duration/ID fieldin all exchanged frames. See 10.3.2.6. This is particularly true for a frame exchange sequence involving more than two STAs (such as the VHT MU PPDU frame exchange sequence, see Figure 10-13 or Figure 10-16), where an individual STA can prematurely exit the group FES, which can affect the timing for when certain procedures are initiated by each STA, and can affect channel efficiency when neighboring STAs with pending transmissions are waiting for the frame exchange sequence to complete.

For example, for each STA, according to 6.5.3.2.4, the scan process can be initiated when a frame exchange sequence is completed. For each STA, according to 6.5.4.2.4, the synchronization procedure can be initiated when a frame exchange sequence is completed. For each STA, according to 6.5.11.2.4, the BSS initialization procedure can be initiated once the current frame exchange sequence is completed. And, for each STA, according to 9.2.4.1.7 and 9.2.4.5.11, the power management mode of a STA is initiated after successful completion of a frame exchange sequence. Nonetheless, this is not a problem as long as the peer STAs are exchanging frames on a wireless medium independent of other STAs. These procedure initiations can occur early and overlap a current frame exchange sequence, or can occur late after a subsequent time delay that follows the termination of the frame exchange sequence and its attendant CDMA/CA-mandated minimum specified duration, see 10.2.2.

This is particularly important when understanding their impact on mechanisms and procedures that are triggered and/or terminated by frame exchange sequence boundaries (see 11.2.6), such as scanning, synchronization, BSS initialization, and power save mechanisms (which cannot be initiated until the current frame exchange sequence is completed, see 11.2.3.1), and power management indications (which cannot be modified until the current frame exchange sequence is completed). In addition, indications that maintain overlapping control with frame exchange sequences of the wireless medium are also impacted by these boundaries. Some of the affected indications include:

1. Power Management subfield
2. Mesh Power Save Level subfield
3. Block Ack Timeout Value field
4. Nominal Minimum TWT Wake Duration field

The purpose of this Annex is to provide examples of frame exchange sequences that depict their usage throughout the various clauses of this standard. This Annex will not cover reference designs or recommended implementations of frame exchange sequences. The examples of frame exchange sequences that will be covered in Annex G include the following contexts:

1. DCF. This example is one in which a minimum specified duration exists between basic frame exchange sequences to gain control of a wireless medium for the duration of a contention-based access period protected by a NAV.
2. HCCA and EDCA. This example is one in which HCF frame exchange sequences are implemented as part of the channel access rules defined by the HCF. See 10.2.3.
3. MCCA. This example is one in which the efficiency of frame exchange sequences is optimized in a mesh BSS.
4. TXOP. This example is one in which frame exchange sequences may be initiated by one or more QoS STAs or an AP in an MU cascading sequence. In this case, a TXOP responder may or may not transmit its frame within the time window of the TXOP, given the estimated time required for transmission of the response frame may be inexact.
5. GCR TXOP. This example is one in which frame exchange sequences may be initiated by one or more APs and/or mesh stations to support the GCR service.
6. Multiple frame exchange sequences in an EDCA TXOP or HCCA TXOP. This example is one in which other mechanisms have overlapping control of the wireless medium with frame exchange sequences.
7. Association of a GLK STA with a GLK AP. This example is one of many in which frame exchange sequences may occur outside the context of an HCF, MCCA or TXOP. Service Period, Announcement Transmission Interval (ATI) and Data Transfer Interval (DTI) are other examples.
8. DMS Request and Response frame exchange to set up GLK-GCR service.
9. Peer-to-peer application. This example is one in which a peer-to-peer application can identify individual frame exchange sequences between HE STAs.
10. Block Ack for VHT PHYs. This example is one in which a single frame exchange sequence includes multiple block acknowledgments, each from a different STA, and each preceded by either a BAR or a VHT MU PPDU transmitted by an AP STA.
11. Restricted Access Window (RAW). This example is one in which a frame exchange sequence shall not exceed the allocated RAW slot boundary.
12. GCR MU-BAR. This example is one in which a frame exchange sequence includes two types of Block Acks for the GCR group members.
13. RD frame exchanges. This example is shown in the informative text of clause O.3.
14. Implicit transmit beamforming. This example is one in which a transmit beamforming frame exchange sequence is initiated by an unsteered PPDU that includes a training request.
15. SU-MIMO and MU-MIMO channel access. This example is one in which frame exchange sequences use MIMO channel access to exchange frames.
16. TXOP-based sectorization operation. This example is one in which spatially orthogonal frame exchange sequences are transmitted until the expiry of the SO timer without resetting the NAV.
17. Sector training. This example is one in which an AP transmits NDP CTS frames, followed by sector ID feedback.
18. Power management in an MBSS. This example shows the unique endings of the frame exchange sequence.

Suggested categories for these frame exchange sequences that will be used for the purpose of examples in this Annex are described below:

1. contention-based access periods (including RTS/CTS) generally the DCF and contention-based HCF

the remaining categories are for protection mechanism-based access periods.

1. Frame aggregation
2. Block acknowledgment
3. Service period)
4. Reverse Direction (see 10.29.1)
5. Beamforming on single spatial stream
6. Point-to-multipoint frame exchanges between an AP STA (the point STA sending a multicast frame) and each of its multipoint STAs (that respond with unicast frames).
7. The abovementioned frame exchange sequences exchange frames within a single wireless medium. Below are for frame exchange sequences that exchange frames across multiple wireless media.

The following table depicts the STA Types that are described as part of the normative description of each FES category. Depending on its capability as described in the normative text, a STA Type that is not described as part of the normative description of a FES Group, might nonetheless support the FES Group. In addition, the FES Groups may not be mutually exclusive. For example, an RTS/CTS protection mechanism used to begin a frame exchange within an EDCA-based TXOP, while the countdown of the NAV timer for the TXOP spans more than one frame exchange sequence, and the TXOP holder determines that start and stop of individual frame exchange sequences within the TXOP (10.23.2.3, 10.23.2.8, 10.23.3.4, 10.50. 26.2.8).

| **FES Grouping** | **STA Types referenced in the FES Group normative descriptions(non-referenced STA Types might be capable of certain FES Groups)** |
| --- | --- |
| **DCF** | **DMG** | **CDMG** | **CMMG** | **GLK** | **EDMG** | **HE** | **S1G** | **VHT** | **HT** |
| Contention-based access period (NAV) | X |  |  |  |  |  |  |  |  |  |
| Protection mechanism-based access period (10.27) | X(RTS/CTS) | X(DMG CTS) |  |  |  | X | X |  | X | X |
| TXOP holder-based access period within a TXOP (10.23.2.8, 10.29.2, 10.50)(EDCA/HCCA/ Reverse Direction) |  | X | X | X |  | X | X | X | X | X |
| Scheduled access period (10.39.6) |  |  |  |  |  | X |  |  |  |  |
| Block acknowledgment (10.25) |  | X | X | X |  |  | X | X |  | X |
| Service period w/ dynamic truncation(Reverse Direction) (10.39) |  | X | X | X |  |  |  |  |  | X |
| Beamforming on single spatial stream (10.33, 10.34, 10.42.1) |  | X | X | X |  | X |  |  | X | X |
| Multi-user MIMO (10.42.10.2, 26.5.3) |  |  |  |  |  | X | X |  |  |  |
| MIMO and spatial sharing across multiple wireless media (10.39.12.4, 10.42.10.2.2) |  | X | X | X |  | X |  |  |  |  |
| Simultaneous Multiband (11.31) |  | X | X |  |  |  |  |  |  |  |
| Transparent Fast Session Transfer |  | X |   | X |  |  |  |  |  |  |
| Traffic Wake Time and Quiet Time Period (10.47) |  |  |  |  |  |  | X |  |  |  |

## Example 1—HE and VHT STA Frame Exchange Sequences with MU acknowledgments

The HE STA and VHT STA are capable of frame exchange sequences that contain multi-user acknowledgments, as described in Clause 10.3.2.13.

### Termination of the frame exchange sequence time interval

For any given multi-user frame exchange sequence (FES), there can be different understandings among the peer STAs that exchange frames about when the FES terminates. For this example, there are two perspectives:

Persepctive #1: The STA that initiates the FES (STA #1, also called the TXOP holder) identifies the end of the FES as the end of a PIFS interval following the last transmission during the FES. The timing for the end of the last transmission of the FES is either pre-determined by the particular FES (e.g., an RTS / CTS exchange) or is scheduled by STA #1 for the current FES (when it schedules BAR frames).

Perspective #2: A peer STA to STA #1 (STA #2) identifies the end of the FES as the end of a PIFS interval following the last transmission during the FES from its perspective. This understanding may differ from STA #1. For example, if STA #1 transmits PPDUs to four different STAs (STA #2 through STA #5) during a single FES, and STA #2’s CCA function indicates the medium is idle while the BlockAcks from STA #3 through #5 are transnmitted, then STA #2 will declare the end of the frame exchange sequence a PIFS interval after its BlockAck transmission. Note, however, that the NAV protection signaled by STA #1 still prevents STA #2 from initiating any transmission until STA #5 has transmitted, regardless of CCA sensing. If STA #2’s CCA function indicates the medium is busy when the BlockAcks from STA #3 through #5 are transmitted, then STA #2 will immediately terminate its FES with STA #1 if it can decode the PPDU, per the normative text. See §11.2.6:

“The STA can determine the end of the frame exchange sequence through any of the following:

* It receives an individually addressed frame addressed to another STA.
* It receives a frame with a TA that differs from the TA of the frame that started the TXOP.

. . .

* The CS mechanism (see 10.3.2.1 (CS mechanism) indicates that the medium is idle at the TxPIFS slot boundary (defined in 10.3.7 (DCF timing relations)).”

These differences in perspective allow for the possibility that a non-TXOP holder may engage scanning, power save, and/or power management mechanisms while the TXOP holder is waiting for BlockAck frames from other non-TXOP holders. This behavior may or may not impact the delivery of re-transmissions from the TXOP holder.

## Example 2—RD frame exchange sequences

***[Editor instruction to copy the text in O.3]***